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A network GVAR model for analyzing maritime transport demand: evidence from freight relationships among Greek ports

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Abstract
The aim of this study is to analyze the freight relationships between three major mainland Greek ports (Piraeus, Thessaloniki and Volos), based on containers' transportation. The methodology used is the Global Vector Autoregressive (GVAR) model. The empirical analysis is based on time series data spanning the period January 1998–December 2012. The most important finding is that a shock in one port doesn't have, in general, a significant impact on any other port and the corresponding effects settle down relatively quickly, usually in less than two months.

Keywords Containers · GVAR · Piraeus Port · Thessaloniki Port · Volos Port

1 Introduction

The rapid growth in recent years of international trade is supported by a parallel growth of maritime international transport. In this context, ports function as nodes, not only in a purely maritime but also in a more complex network. As the volume of goods transported grows, demand interrelations among various ports are being observed. Co-operation and competition among ports depends both on static factors such as geographic location, distance between ports and their potential to serve a common hinterland [1] as well as on dynamic factors including port, road and rail infrastructures.

Despite the global maritime booming, Greek Ports have not yet gained the market share that corresponds to their favourable geographic location as a connecting hub between Asia and Europe [2], mainly because infrastructure shortcomings limit their competitiveness [3]. This role will be fully achieved only if considerable investments take place, improving operations and capacity expansions and, also, if the connecting road and railway networks will be considerably upgraded [4]. Port investment policy will be more effectively planned if the major Greek ports are examined as interconnected nodes of a port system rather than isolated nodes.

This study explores economic relationships and demand interconnections among three major mainland Greek ports, namely Piraeus, Thessaloniki and Volos, as opposed to other studies which examine demand evolution for individual ports (see, for example, [5]). A global vector autoregressive (GVAR) model is used to investigate the complex interrelations that govern fluctuations in demand in the ports examined. Our study examines how container demand in one geographic area can affect the conditions in a second area, characterized by the same macroeconomic conditions. A thorough understanding of these relations is essential for the effective planning of future infrastructures and the capacity

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of ports. In this way, the analysis could contribute towards the adoption of policies across different ports that are either competitive or cooperative.

In this context, Vector Autoregressive (VAR) models and, in particular, the GVAR provides a methodology for investigating the dynamic interlinkages among economic units of different geographical areas. Additionally, the GVAR framework provides the tool for analyzing the effects of unexpected shocks among the various economic units. In practice, it is an econometric model, which has been specifically designed for expressing economic inter-relationships.

In the transportation field, the GVAR methodology has been implemented to analyze public transport demand of the multimodal system of Athens [6]. In the present work, the GVAR model combines the different VAR models, for each one of the ports concerned, to one complete econometric model. The link between the number of containers that arrive at each port (endogenous variables) is investigated, while the exogenous variables unemployment, trade, credit, Gross Domestic Product (GDP), London interbank offered rate (LIBOR), fleet development, and fuel price included in the analysis, act as transmission mechanisms of shocks. The degree of interdependence among the different ports is assessed through the analysis of impulse response functions. Thus, the study emphasizes the need to analyze container demand fluctuations of different ports simultaneously and proposes a larger econometric model to investigate cooperation and competition among ports taking also into account the macroeconomic conditions at the national and international level.

2 Related studies

As far as the impact of exogenous factors is concerned, transformations in the macroeconomic environment significantly affect container port throughput [7]. According to [8], world economy, international trade, average achieved profit, political events and transport costs are the main factors that affect maritime demand. Utilizing a wide range of approaches, the literature has examined a number of variables that affect container volumes. Chou et al. [9] investigated the relationship between the container volumes in Taiwan and various macroeconomic variables. In their study, [10] used both statistical analysis and neural networks and concluded that the number of containers in Thailand is significantly affected by GDP, world GDP exchange rates, population and fuel price. Using real container volume data from 1990 to 2008 in Taiwan, [11] employed a system dynamics model involving GDP and international trade-related factors as independent variables. Unemployment rate, GDP and Purchasing Power Parity (PPP) were used as macroeconomic indicators of container throughout in the port of Koper. The results revealed that more accurate forecasts can be achieved by including macroeconomic variables in the model [12].

Apart from the impact of the exogenous variables on containers' volume, the interrelation of port throughput between different ports has been investigated in the literature. Gianfranco et al. [13] investigated competition and possible cooperation between seaports in an aggregate level. Clustering analysis was used to identify homogenous groups of ports and propose cooperation policies to the ports that belong to the same cluster. Hierarchical cluster analysis has also been used to classify container terminals in Brazil into groups based on a great variety of criteria, including number of containers and berth length [14]. At the disaggregate level, the VAR methodology was implemented to analyze interrelations among container port throughput of different industrial sectors for the Port of Sydney. Paflioti et al. [7] concluded that fluctuations at the aggregate level are closely related to the interrelations across the different container sectors (disaggregate level) and pointed out that the industrial sectors react differently to external shocks.

In another important work, a method was proposed for the estimation of containerised flows internationally. By using the proposed procedure, two different models are combined: (1) a meso-aggregated model for estimating flows by using a specification-calibration–validation process; and (2) a macro-aggregated model for estimating flows by using recalibration methods. The procedure has been tested with the purpose of estimating the containerised flows of a geographic area containing countries bordering the Mediterranean basin. For researchers developing freight models, the integrated procedure is an effective support because it allows them to combine the potentialities of specification-calibration–validation and re-calibration processes in freight demand modelling [15].

Furthermore, another interesting study explored how short sea shipping services can be utilized to meet economic, social, and environmental needs as a competitive, sustainable approach to freight transport. The article proposed a methodology for assessing competitive transportation alternatives in the Mediterranean basin, using a discrete choice aggregate model. In order to evaluate the potential of short-sea shipping (SSS) and the net benefits derived from lower external costs in the north-west Mediterranean basin, a relevant methodology was applied. A two-point scenario was considered: the introduction of new SSS services as envisaged by current EU projects, as well as the introduction of new SSS routes and a significant increase in the frequency of existing SSS services. The project proved to be highly effective in shifting freight traffic from the road network as well as in providing external benefits [16].

Finally, spatial econometrics has been recently used to identify complementary or substitutionary demand relationships between ports [17] but spatial econometric models are actually limited for explaining causality. Konstantakis et al. [5] investigated the determinants of maritime transport fluctuations in the three major ports in Greece, using the concept of causality. However, relations among the containers volume of the different ports were not analyzed. In this context, the GVAR methodology is used to analyze interdependencies among Greek ports by taking also into account the impact of the exogenous variables on containers' demand.

3 Data

3.1 Ports included in the analysis

Greece, has a long and strong tradition in shipping, mainly due its geographical position being at the shipping crossroad of three different continents. Most ports of Greece are state owned, and the largest port of the country and the largest in terms of its containers in the Mediterranean Sea is the port of Piraeus. The Piraeus port is a valuable resource for the Greek economy as a whole and the local economy in particular. Being relatively close to the Suez Canal is a preferable gate in Europe for Asian products. On the other hand, the port of Thessaloniki is both a crucial and strategic port for the Balkans in general since it serves as the main gate for containers before being handled by other road and rail transportation means. Volos used to be an option to both Piraeus and Thessaloniki, and the ports of Igoumenitsa, Kavala, and Alexandroupoli were strengthened due to the development of the "Egnatia" street.

It is worth noting that Greece has an average share of containers' that account for more than 6% of the total containers that arrive in various Mediterranean ports, whereas the port of Piraeus historically handles on average more than 5% of total containers' that arrive in Greece. The respective value for the port of Thessaloniki is roughly 1%. Given that its infrastructure is nearly half that of other Mediterranean ports, the port of Thessaloniki has tremendous potential for growth in the future [4]. Moreover, new significant projects like the direct railway connection among Sofia and Thessaloniki are expected to create new competitive advantages for the port of Thessaloniki.

3.2 The sample

In the empirical analysis, monthly time series data are used spanning the period 1998–2012, for three main mainland Greek ports, namely Piraeus, Thessaloniki and Volos. Figure 1 illustrates the Input and Output variables, used in the analysis. Table 1 presents the variables used in the analysis, and Table 2 gives an overview of the data used and the econometric framework undertaken. The empirical analysis is based on the total number of containers in the ports examined, expressed in thousands of items for the period 1998–2012. This includes imports and exports, transshipments as well as emptying and filling activities. The total number of containers in the Piraeus port does not include the containers managed by the Chinese Company COSCO since April 2010.

Data concerning the number of containers for Piraeus, Thessaloniki and Volos were obtained from the Department of Statistics of the Piraeus Port Authority S.A., the Department of Information Technology and Communication of the Thessaloniki Port Authority S.A., and the Department of Statistics of the Volos Port Authority S.A. Data that refer to the total number of containers and also to international trade and international credit come from the World Bank (databank.worldbank.org). Finally, data that refer to LIBOR, oil price, exchange rate USD/EUR, and fleet development data come from the Federal Reserve Bank of St. Lewis.

The input and output variables chart in Fig. 1, illustrates the variables that are used in the analysis. GVAR output variables are the "domestic" variables to the system network, in the sense that they describe magnitudes whose values are

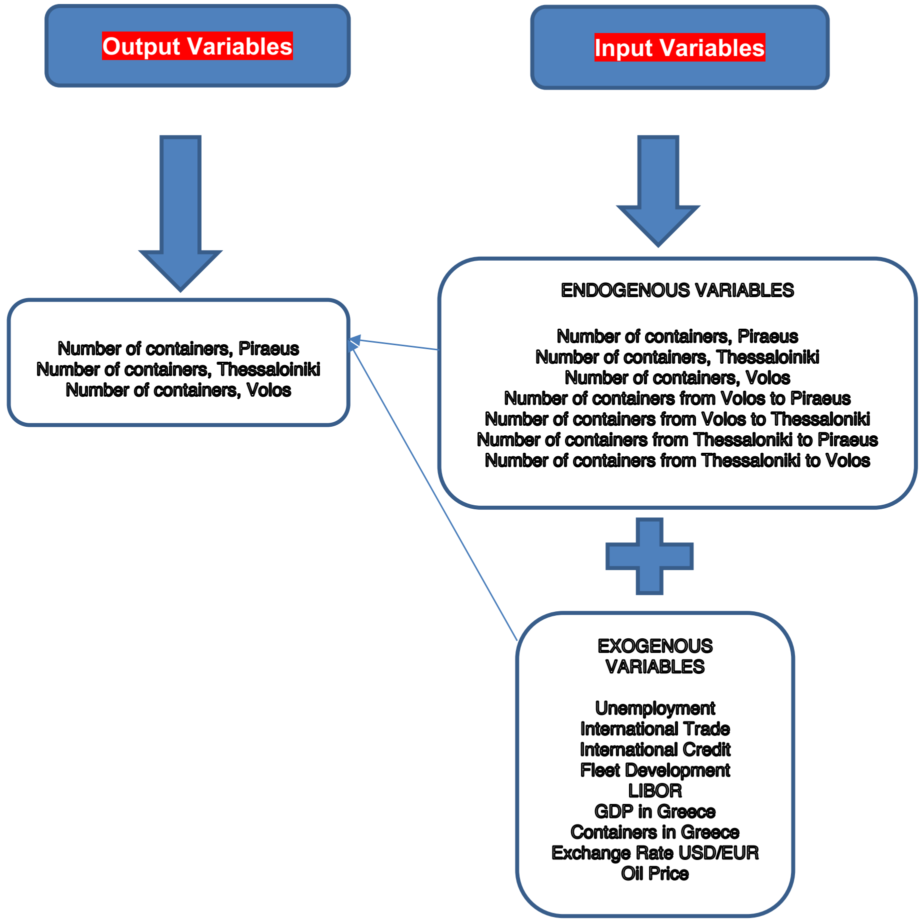


Fig. 1 Input and output variables chart

Table 1 Variables included in the analysis

Endogenous	Exogenous
Number of containers that arrive at the port of Piraeus	Unemployment
Number of containers that arrive at the port of Thessaloniki	Volume of international trade
Number of containers that arrive at the port of Volos	Volume of international credit
Number of containers transported from the port of Volos to the port of Piraeus	Fleet development
Number of containers transported from the port of Volos to the port of Thessaloniki	LIBOR
Number of containers transported from the port of Thessaloniki to the port of Piraeus	GDP
Number of containers transported from the port of Thessaloniki to the port of Volos	Volume of containers that arrive in Greece
	Exchange rate USD/EUR
	Oil price

dependent on other variables. Each of these variables appears as a dependent variable in the system network. Other variables, namely input variables to the system network, can be divided into two (2) basic categories. Among the endogenous variables are the "domestic" variables as well as the "weighted" variables, which reflect the part of the "domestic" variables that are transmitted between ports. "Exogenous" variables are also included, since their values are independent of the system network investigated and are external to it. In other words, they are rather independent variables that affect the output, i.e. "domestic" variables.

Table 2 Data source and techniques implemented

Econometric techniques	Time period	Data Sources
Unit root test	1998 (M1)–2012 (M12)	Department of Statistics, Container Terminal Department, Piraeus Port Authority S.A
Lag selection		Department of Information Technology and Communication, Thessaloniki Port Authority S.A
GVAR estimation		Department of Statistics, Volos Port Authority S.A
Stability analysis		World Bank open data
GIRF		Federal Reserve Bank of St. Lewis

4 Methods

In what follows, an overview of the econometric techniques to be used will take place.

4.1 The node theoretic-GVAR model

It is necessary to make some assumptions so as to set up the relevant GVAR model. The first step in creating a multi-entity model is to define its network structure. Accordingly, Definition 1 that follows below, describes the structure of the network.

Definition 1 An economic system can be represented as a network of $i = 1, \dots, N$ nodes, each one representing a port. Trade weights can reveal the bilateral trade position in each trade market between each node in this trade network. The edges of the network bind each entity with the rest of the entities.

Based on Definition 1, each unit in the network is depicted as a single node and its inherent characteristics are depicted by a vector y_i. Note that the vector of characteristics could vary from node to node. Next, Assumption 1 that follows defines the time dimension.

Assumption 1 The network is a dynamic one, which is subject to change based on changes in the elements of the trade weight matrix over time.

Now, we make Assumption 2 about the network's structure.

Assumption 2 The number of network entities is assumed to remain constant over time, such that no entity can enter or exit the network at any time.

We proceed by building the econometric framework of our analysis. It should be noted, that based on our network structure the direct linkages among the various ports are explicitly modelled. Nonetheless, there could also be indirect linkages that also need to be modelled. To do so, we will make use of unobserved factors in our modeling approach. Let us assume a canonical factor model:

$$y_{it} = \Gamma_i f_t + \xi_{it} \quad i = 1, \dots, N, \tag{1}$$

where: Γ_i denotes the factor loadings matrix that captures the links between the nodes. Here, Γ_i is assumed to be bounded, and ξ_{it} expresses the financial market shocks. These are assumed to follow:

$$\Delta f_t = \Lambda_f(L)\eta_f, \quad \eta_f \sim IID(0, I) \tag{2}$$

$$\Delta \xi_{it} = \Xi_i(L)\omega_{it}, \quad \omega_{it} \sim IID(0, I) \tag{3}$$

Λ_f & Ξ_i are absolute summable, so both $Var(\Delta f_t)$ and $Var(\Delta \xi_{it})$ do exist.

Based on the aforementioned assumptions, the common factors can be estimated as cross section average combinations of the observables y_{it}, following [18] as:

$$y_{it}{}^* = W_i^{'y_{it}} = \Gamma_i{}^* f_t + \xi_{it}{}^* \tag{4}$$

Equation (4) can be viewed as a VARX for each port in the network using:

$$y'_{i,t} = a_{i0} + +\Phi(L_1) y'_{i,t}{}^* + \Phi(L_2) g'_{i,t} + u_{i,t}, i \epsilon \{1, .., N\}, \tag{5}$$

where $i = 1, \dots, N$ are the port entities in the network; a_{i0} is the vector of intercepts, $y'_{i,t}$ is the transpose vector with dimension $(1xm)$ for the m variables for each node which expresses the ports' entity (node) specific variables; $y'_{i,t}{}^*$ is the transpose vector of m foreign-specific variables for each port with dimension $mx1$, whereas $\Phi(L_1)$ is an mxL_1 lag polynomial matrix; $g'_{i,t} = [g_{i_1}, \ldots, g_{i_p}]$ is the transpose vector of p global variables with dimension $px1$ while $\Phi(L_2)$ is a pxL_2 lag polynomial matrix. Lastly, $u_{i,t} \sim N(0, \sigma^2)$.

The GVAR model is estimated using an equation-by-equation approach, which is based on the OLS model. As a result of an unexpected or unanticipated shock equal to one (1) Standard Deviation (S.D.) to one of the variables in the model, the Generalized Impulse Response Function (GIRF) explains what will happen to the other variables in the model in response.

Naturally, a number of relevant tests must be run in order to estimate the GVAR model.

4.2 Stationarity

Using the usual notation, we start our study by checking for unit roots using the well-known Augmented Dickey-Fuller (ADF) methodology, based on the equation:

$$\Delta \Upsilon_t = \alpha + bt + \rho Y_{t-1} + \sum_{i=1}^{m} \gamma_t \Delta \Upsilon_{t-1} + \varepsilon_\tau$$

where: Δ is the first difference operator, t is time and ε is the error term. In case of rejecting the null hypothesis $H_0 : \rho = 0$ then the variable Y_t should be considered to be stationary.

4.3 Lag length

The Schwartz-Bayes Information Criterion (SBIC) was employed for selecting the optimum lag length:

$$\hat{k} = argmin_{k \le n} \left\{ -2\frac{\ln(LL(k))}{n} + k\frac{\ln(n)}{n} \right\}$$

where: LL(k) is the log-likelihood function of a VAR(k) model, n is the number of observations and k is the number of lags and $\hat{k}$ is the optimum lag length selected.

5 Results

We begin by visual inspection of the node–theoretic structure of the model in Fig. 2, which is a node diagram, and the size of each node, i.e. port, is proportional to its relative importance in the network.

As a visual representation, the node diagram presented in Fig. 2 maps a network of interconnected entities or nodes, namely the Greek ports under investigation. We have proposed a diagram that organizes data in a way that allows us to quickly identify relationships and key nodes in this network of ports. By analyzing the node diagram, we find out which ports are the most important and how they are interconnected within the Greek mainland ports network. According to the node representation in Fig. 2, all of the ports are directly interconnected to each other and the largest port is the Piraeus port, which is the most important of them all.

We continue by assessing the stationarity properties of our variables using the ADF unit root test. The results are presented in Table 3. The null hypothesis was rejected at the 5% level for all the endogenous variables, indicating that

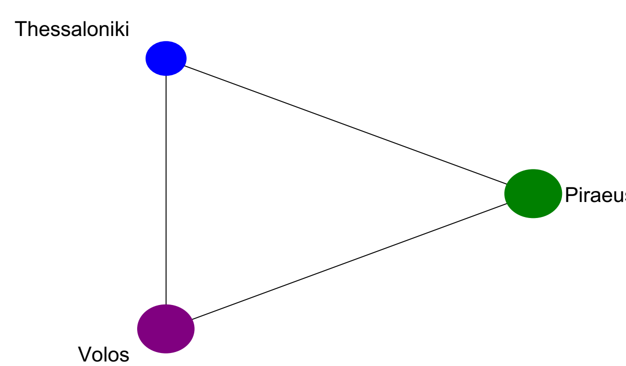


Fig. 2 Network visualization between the three major ports

Table 3 Unit root tests

Unit root test (level)			Unit root test (First differences)	
Variables	Probability	Stationarity	Probability	Stationarity
Endogenous				
Number of containers that arrive in Piraeus	0.0393	Yes	–	–
Number of containers that arrive in Thessaloniki	0.0002	Yes	–	–
Number of containers that arrive in Volos	0.0000	Yes	–	–
Number of containers transported from the port of Volos to the port of Piraeus	0.0000	Yes	–	–
Number of containers transported from the port of Thessaloniki to the port of Piraeus	0.0000	Yes	–	–
Number of containers transported from the port of Thessaloniki to the port of Volos	0.0000	Yes	–	–
Number of containers transported from the port of Volos to the port of Thessaloniki	0.0000	Yes	–	–
Exogenous				
Unemployment rate	0.9970	No	0.0000	Yes
Volume of international trade	0.3630	No	0.0000	Yes
Libor	0.8310	No	0.0000	Yes
Fleet development	0.9925	No	0.0000	Yes
Credit	0.0000	Yes	–	–
GDP	0.0000	Yes	–	–
Oil price	0.0321	Yes	–	–
Exchange rate USD/EUR	0.4627	No	0.0000	Yes
Number of containers that arrive in Greece Greece	0.0000	Yes	–	–

these variables are integrated of degree zero (0), i.e. I(0). The same applies for some of the exogenous variables, including credit, GDP, oil price, and total number of containers that arrive in Greece.

The rest of the exogenous variables (Unemployment rate, Volume of international trade, LIBOR, fleet development, exchange rate USD/EUR) were found to be non-stationary in levels. When the test is applied to the variables' first differences, the t-statistics for the first differences are statistically significant, which results in the rejection of the null hypothesis and shows that these variables are I(1). Since all the endogenous variables are stationary, cointegration tests are not applied.

The next step of the analysis includes the selection of lag length of each port, based on the Schwarz-Bayesian information criterion. In Table 4, the number of lags that need to be included in the VARX models is found to be the same for all the ports and equal to one.

Based on the estimation results of the various VARX models for each port investigated, Table 5 presents the effects of the exogenous variables on the port specific variables. In this context, the cargo volume of Piraeus port is, as expected, positively and statistically significantly affected by an increase in the World Trade Volume, the Greek GDP, the fleet

Table 4 Lag length selection for the VARX Model

Variables	Port	Lags	SBIC
Number of containers that arrive in the port of Piraeus	Piraeus	1	143.795
Number of containers transported from the port of Volos to the port of Piraeus			
Number of containers transported from the port of Thessaloniki to the port of Piraeus			
Number of containers that arrive in the port of Thessaloniki	Thessaloniki	1	128.438
Number of containers that arrive in the port of Piraeus			
Number of containers transported from the port of Volos to the port of Thessaloniki			
Number of containers that arrive in the port of Volos	Volos	1	150.41
Number of containers that arrive in the port of Piraeus			
Number of containers transported from the port of Thessaloniki to the port of Volos			

Table 5 Effects of exogenous variables on the VARX/VECX model of each port

Exogenous variables	Piraeus Port	Thessaloniki Port	Volos Port
Unemployment	84.28	28.87	−4.109
	(0.34)	(0.46)	(−0.64)
Trade	0.527**	−0.0127	−0.00248
	(2.69)	(−0.30)	(−0.35)
Libor	−2151.5***	113.8	−17.10*
	(−3.57)	(1.40)	(−1.75)
Fleet Development	13.50**	0.539	0.108
	(3.19)	(0.68)	(0.85)
Credit	−2.222	0.593	0.0213
	(−1.05)	(1.05)	(0.34)
GDP	264.9***	23.06*	−0.553
	(3.88)	(1.69)	(−0.42)
Oil Price	−175.4**	22.80*	−1.624
	(−3.12)	(1.69)	(−1.17)
Total Containerships	0.0113***	0.00142***	−0.00001
	(8.09)	(3.41)	(−0.27)
Exchange Rate	5408.2	−1244.2	46.12
	(0.91)	(−0.96)	(0.34)

t statistics in parentheses

* $p < 0.10$, ** $p < 0.05$, *** $p < 0.01$

development and the total number of containerships. On the other hand, Piraeus Port is negatively and significantly affected by an increase in the price of oil, and in the price of LIBOR, whereas Greek unemployment and Exchange Rate of EUR/US plays no statistically significant role. Turning to the port of Thessaloniki, based on our findings the only statistically significant effects are those generated by the Greek GDP and the total number of containerships. Finally, cargo volume in the port of Volos is positively affected only by the price of LIBOR.

Next, Table 6 shows the contemporaneous effects in their port specific counterparts. In this context, based on our findings, the cargo volume of Thessaloniki port affects positively and statistically significantly the containership volume in the port of Piraeus and vice versa, implying a complementarity effect between the two ports. The same complementarity effect seems to be in place between the containership volumes in the ports of Thessaloniki and Volos. Finally, the containership volume in the port of Volos is negatively and statistically significantly affected by the port of Piraeus. It is worth noticing that the containership volume in the port of Piraeus affects both Volos and Thessaloniki ports. However, the opposite direction does not necessarily hold, giving credit to the view that Piraeus port dominates the rest of the ports in our analysis.

The next step of the analysis is to determine the stability conditions of each VARX by checking whether the roots of the system lie inside or on the unit circle.

Table 6 Contemporaneous Effects of Foreign Variables on their Port specific counterparts

	Piraeus Port	Thessaloniki Port	Volos Port
Piraeus Port*		6.549***	−0.866**
		(4.12)	(−2.96)
Thessaloniki Port*	40.93***		0.0000437***
	(7.00)		(6.53)
Volos Port*	−112.6	97.09**	
	(−1.51)	(1.97)	

t statistics in parentheses

* $p < 0.15$, ** $p < 0.05$, *** $p < 0.01$

Fig. 3 VARX Port of Piraeus stability

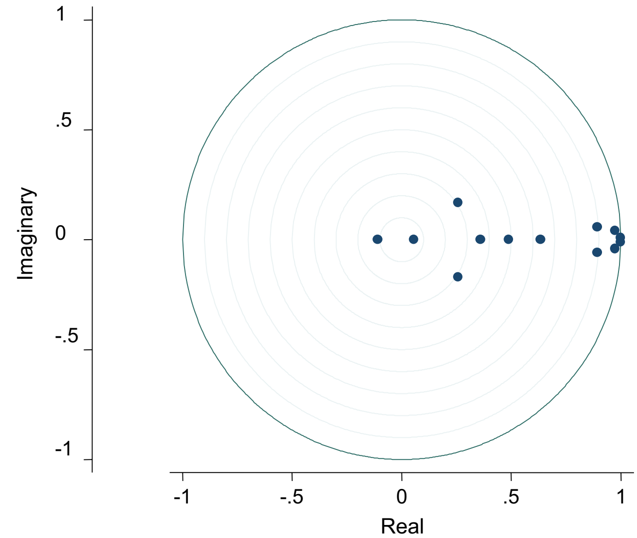


Fig. 4 VARX Port of Thessaloniki stability

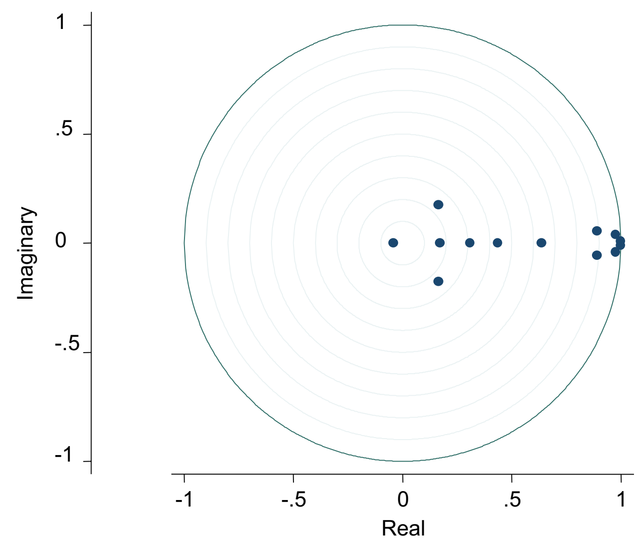
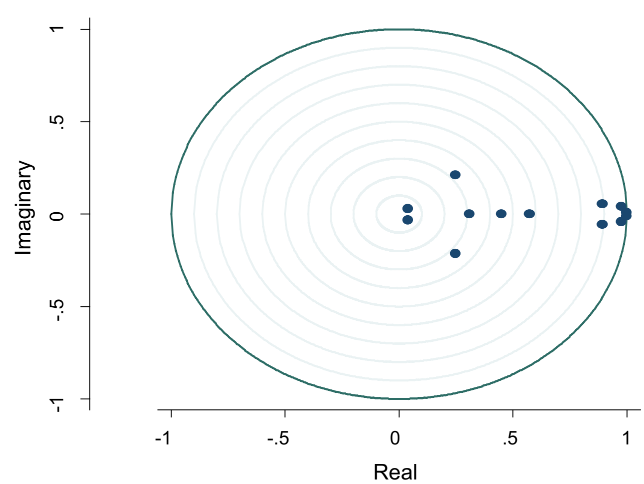


Fig. 5 VARX Port of Volos stability



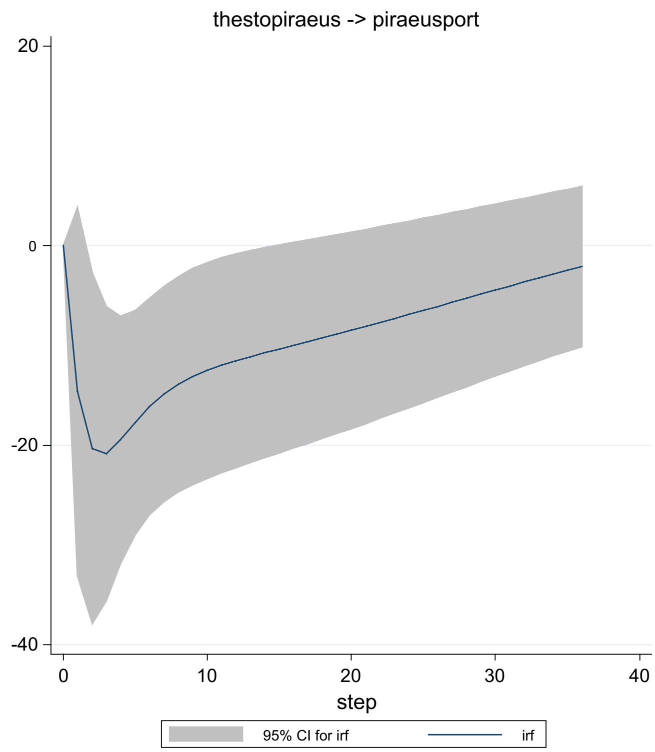


Fig. 6 GIRFs Port of Piraeus

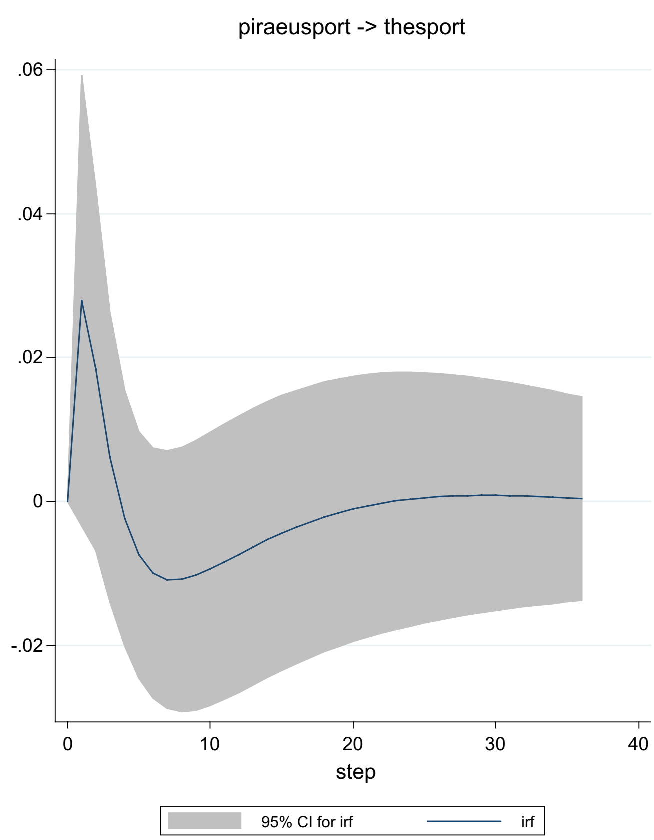


Fig. 7 GIRFs Port of Thessaloniki

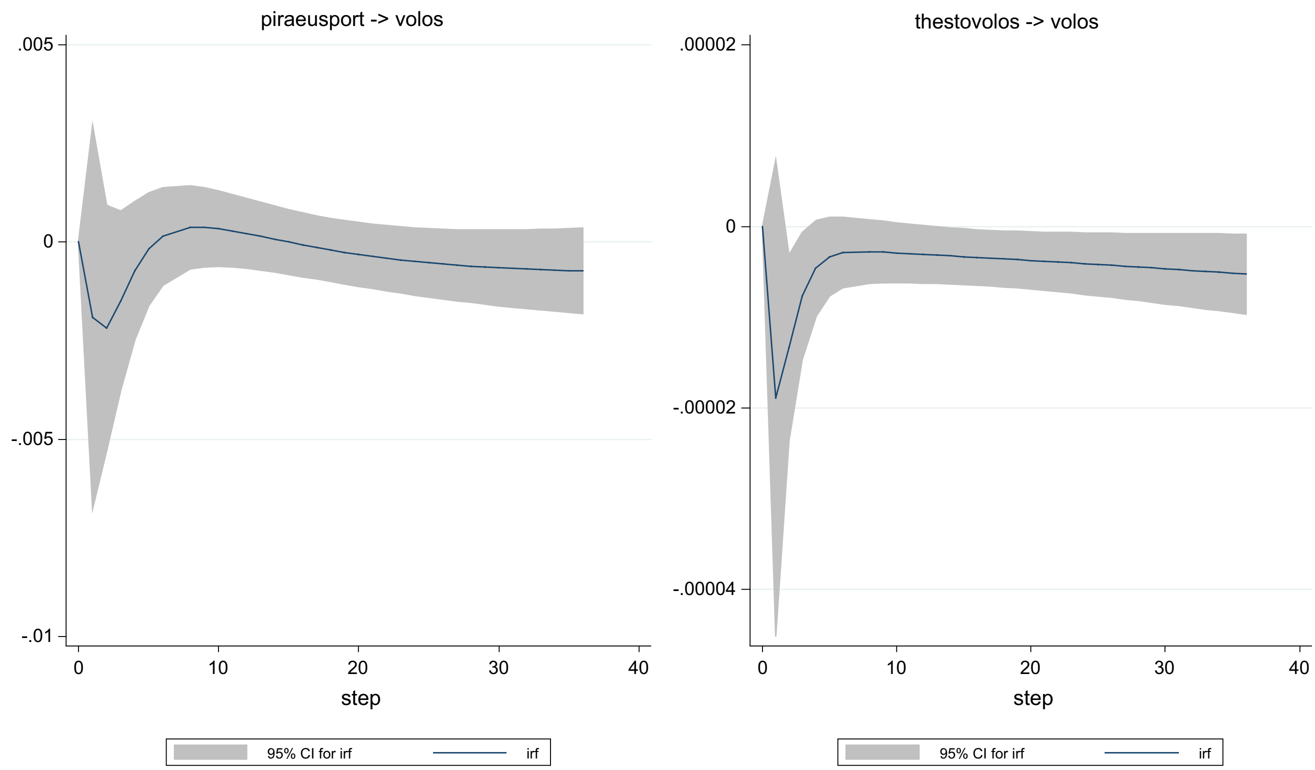


Fig. 8 GIRFs Port of Volos

First, the stability of the port of Piraeus was analysed (Fig. 3) and then that of the port of Thessaloniki (Fig. 4). Finally, the stability for the port of Volos is presented (Fig. 5). We can see that the GVAR model presented is stable, based on its eigenvelues.

The Generalized Impulse Response Functions (GIRFs) allow us to analyze the effects and reactions of containership traffic to an unexpected shock in one port. Since VARX satisfies the stability condition, the GIRFs (Figs. 6, 7, 8) tend to return to their equilibrium positions.

5.1 Piraeus

As far as the port of Piraeus is concerned, the endogenous variables that are being subjected to the shock are the total number of containers transported from Thessaloniki to Piraeus as well as the total number of containers transported from Volos to Piraeus.

According to Fig. 6, a shock in the number of containers transported from Thessaloniki to Piraeus port has a negative impact on the number of containers that arrive in Piraeus, which is maximized during the first three months and then at a slow rate reaches the equilibrium position. This finding indicates that the port of Thessaloniki could act temporarily as a substitute to the port of Piraeus, especially given that there is room for infrastructure development [4].

On the other hand, a shock in containers that are transferred from the port of Volos to the port of Piraeus, has a positive impact on the number of containers in Piraeus port that lasts for approximately 2 months and then it is stabilized at the level reached for a 2-year time period. The equilibrium position is reached in approximately 3 years. The impact, although temporary, is relatively high indicating that there is an interrelation between the two ports. The direction of the relationship is probably related to the fact that a large volume of the containers that arrive in Piraeus are transshipments. The percentage of transshipment in the port of Piraeus is relatively high (76%) a fact which, in combination with the model results, indicates that Piraeus port acts as an intermediate node for the Volos port containers.

5.2 Thessaloniki

In the model of Thessaloniki's port, the endogenous variables that are subjected to a shock are the total number of containers transported to Piraeus as well as those transported from Volos to Thessaloniki. The respective impact on the Port of Thessaloniki is presented in Fig. 7.

According to Fig. 6, a shock in the number of containers transported to Piraeus causes a small positive effect on the containers of Thessaloniki in the first month and then a negative effect that is maximized approximately after 8 months. The equilibrium point is reached in a 2-year time period. The small effect is probably explained by the fact that although there is some interaction between the two ports, they serve different geographic areas. After all, Thessaloniki is a gateway for goods' import to the Balkans, Turkey and the Black Sea.

On the other hand, a shock in the number of containers transported from Volos to Thessaloniki has a negative influence on the port of Thessaloniki lasting for two months. The equilibrium position is reached at the end of the third year. This indicates that these two ports function in a competitive way, which is supported by the fact that they are closely located.

5.3 Volos

Figure 8 presents the effects to the port of Volos from a shock either in the number of containers that arrive in Piraeus or in the number of containers transported from Thessaloniki to Volos Port.

Results indicate that a shock in the number of containers that arrive at Piraeus Port have a small negative effect on the number of containers that arrive in Volos, which after the first two months reach the equilibrium position. Moreover, according to Fig. 8, a shock in the containers' movements from Thessaloniki to Volos causes a small negative effect on the total number of containers that arrive in Volos, which dies out in two months with containers arriving at Volos reaching the equilibrium position. Second, Volos port has a dedicated local market over which it has a location advantage. The finding that competition is constrained by the fact that many ports have a dedicated local market is consistent with other studies [19, 20]. Despite the various shocks induced, the effects shown in Figs. 6, 7, 8 begin to stabilize quite fast, typically in less than 2 months. This result suggests that the model is stable, and the relevant stability analysis confirms this.

6 Discussion and policy recommendations

As far as interdependencies between the two large Greek ports are concerned, the results of the study indicate that a shock in Piraeus has a small positive impact on Thessaloniki, in the short run. This is probably due to the fact that it functions as a transshipment node. The reverse is not true; it seems that increased shipments to Thessaloniki have a negative effect on Piraeus, indicating that Thessaloniki functions in a rather autonomous way restricting transshipment from Piraeus Port. However, competition between these two large ports remains limited, a fact that is observed in the results of the model developed. The main factor that limits competition between the two large ports of Greece is the fact that they serve different geographic areas. Thessaloniki is in a privileged position to serve the countries located North of Greece, namely the Balkans, whereas Piraeus serves the Attica region and acts also as a transshipment node competitively to other large European ports, since it is close to the basic route Gilbraltar-Souez. Another reason that causes limited competition is the fact that the railway network did not serve effectively the Piraeus port and, thus, connection to Central and Northern Greece from Piraeus port was mainly through the road network. Taking this into account, Piraeus was not considered to be a good alternative to Thessaloniki Port.

As far the Port of Volos is concerned, it was found that a shock in the number of containers from Volos to Piraeus increases significantly the containers that arrive in Piraeus Port, while the reverse is in force for the Port of Thessaloniki. More specifically, a shock in the number of containers from Volos to Thessaloniki has a negative impact on the containers that arrive at Thessaloniki Port. Thus, Volos seems to function in a cooperative way to Piraeus and in a competitive way to Thessaloniki. This is probably because Piraeus serves Volos as a transshipment node. On the other hand, since Volos is closely located to Thessaloniki, it is natural that there is some degree of competition between the two ports. However, the results show that although Volos port could act as an alternative to Thessaloniki, the dedicated market it serves and the limited capacity of the railway network, restrict competition, at a significant extent.

The extent to which different ports function in a competitive or cooperative way depends on various factors such as port governance, road and railway infrastructure and related inland costs. Greek ports are currently undergoing both a privitisation process and an infrastructure development, which—together with the railway and road development -, is expected to increase their container throughput and also affect the flows through the ports. Although these factors change dynamically and may affect demand interrelations between ports, this effect is expected to be limited in the case of Greek ports because of their geographic location and the different markets they serve. The limited competition and cooperation among Greek ports revealed in the present study is also supported by the fact that the corresponding shocks in demand settle down in less than two months indicating that a shock in one port doesn't have, in general, a statistically significant impact on any other port.

7 Conclusion

Piraeus Port is by far the largest Greek port and mainly functions as a transshipment node, because it is favourably located to act as a hub between Asia and Europe and partly because the railway line serving the port was not adequately developed. Thessaloniki Port is the second largest port and has a privileged location in serving the countries in the north of Greece and especially the Balkans, while Volos is closely located to Thessaloniki Port and mainly serves the province of Thessaly.

In this paper, we investigated interdependencies among different ports of Greece that are characterized by the same macroeconomic environment. A GVAR model for container demand was developed in order to explore how container demand in one geographic area can affect the corresponding variations in another area.

Although demand interconnections among the three major Greek ports have been observed, the deviations from the initial equilibrium positions are rather small and seem to settle down quickly. This fact indicates that the large ports of Greece function, to a great extent, in an autonomous way, since they serve different markets.

The inter-relations among the three main ports of Greece that were examined are expected to change in the future. The construction of the "Egnatia" road axis, the improvement of Greece's rail infrastructure, and the completion of the Sofia-Thessaloniki rail and road network are all anticipated to enhance transit cargo traffic in Greece. The above infrastructure development, in combination with the ports' privitisation process, will probably lead to changes in the port demand inter-relationships. To this end, current results may provide a useful measure of comparison when these new conditions reach maturity. Cleary, future research would be of interest.

Author contributions The analysis of the data is performed by HG, the discussion of the results in the relevant context is carried out by CM, the inception, methodology selection, supervision and writing of part of the text are carried out by PGM, while the quantitative exploration is carried out by KNK. All authors read and approved the final manuscript.

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Data availability The datasets generated and/or analysed during the current study are available from the corresponding author on reasonable request.

Declarations

Competing interests On behalf of all authors, the corresponding author states that there is no conflict of interest.

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